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GA-C24623
MARCH 2004

TEST REPORT – DIRECT PART MARK TEST PROGRAM
IMPROVED DIRECT PART MARK SURVIVABILITY TEST PROGRAM
FOR
NORMAL AIRCRAFT LANDING GEAR PART OVERHAUL CONDITIONS

PREPARED
FOR
OO-ALC/LGHEL

BY

AGING LANDING GEAR LIFE
EXTENSION PROGRAM

PREPARED UNDER
CONTRACT GS-23F-0150L
FOR OGDEN AIR LOGISTICS CENTER
HILL AFB, UTAH

PROJECT 39135

GENERAL ATOMICS

GA-C24623
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SIGNATURE PAGE

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AGING LANDING GEAR LIFE
EXTENSION PROGRAM

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INTRODUCTION

Under the Aging Landing Gear Life Extension (ALGLE) Program, a test program was conducted to evaluate the survivability of improved machine readable marks and human readable marks applied with direct part marking (DPM) processes for normal aircraft landing gear part overhaul conditions. OO-ALC/LGHEL is working to qualify DPM processes for marking recoverable landing gear parts. The test program was to determine if the machine readable marks and/or human readable marks provide lifetime traceability for landing gear parts by surviving normal aircraft landing gear part overhaul conditions.

For the test program, several guidelines were considered. The primary guidelines were: the mark(s) and reader(s) or operator(s) must provide lifetime traceability for landing gear parts; the machine readable mark(s) and reader(s) must compete with the human readable mark(s) and operator(s) through increased traceability and efficiency; and the mark(s) and reader(s) must function as an automatic identification and tracking technology to assist an operator in collecting data directly from landing gear parts in an overhaul environment.

The secondary guidelines were: the test program should focus on finding robust marks with the minimum depth required to survive an overhaul environment. If possible, the test program should focus on finding a single optimum mark for landing gear parts.

The tertiary guidelines were: the new DPM processes should compete with the current DPM processes through increased traceability and efficiency. The current DPM processes for landing gear parts include vibropeening and impression stamping human readable marks.

The test program was a research and development effort that addressed several recommendations from a previous test program on the survivability of machine readable marks under normal aircraft landing gear part overhaul conditions. The final report for the previous test program was entitled *Direct Part Mark Survivability Test Program for Normal Aircraft Landing Gear Part Overhaul Conditions GA-C24577*, and herein it is referred to as the previous test program. The previous test program identified dot peen, micro mill, and laser engrave marks for further development and testing. The focus of the current test program was: to develop and evaluate mark improvements related to the mark cell shape and the mark depth; to evaluate mark survivability improvements for abrasive blasting processes; to evaluate mark survivability for shot peening; to review the problem of reading a mark through protective plating and/or paint; and to compare machine readable marks to human readable marks. The test program used marks on coupons and focused on processing the coupons as though the marks were applied to the marking surfaces of a landing gear part. If robust marks or an optimum mark were found, then more detailed testing could be conducted to include more materials, more surfaces, more topographies, multiple overhaul conditions, and condemned landing gear parts.

The test program did not consider the full complexity of adapting a serial number tracking system based on machine readable marks. Implementation considerations include developing DPM process specifications, developing standard mark data content, identifying the mark locations for each part, addressing whether the mark location would require a drawing revision or whether the mark location would be incorporated into secondary documentation such as technical orders. The test program did not consider mark repairability, since the marks are intended to provide lifetime traceability and become a permanent feature of a part. The test program did not conduct any mark and material characterization to investigate degrading effects of the marks on the material. The test program did consider a return on investment analysis. The test program did not consider the full complexity of adapting a serial number tracking system based on machine readable marks, but the test program was a necessary requirement to review the technology and to provide a data package to assist in the decision making processes.

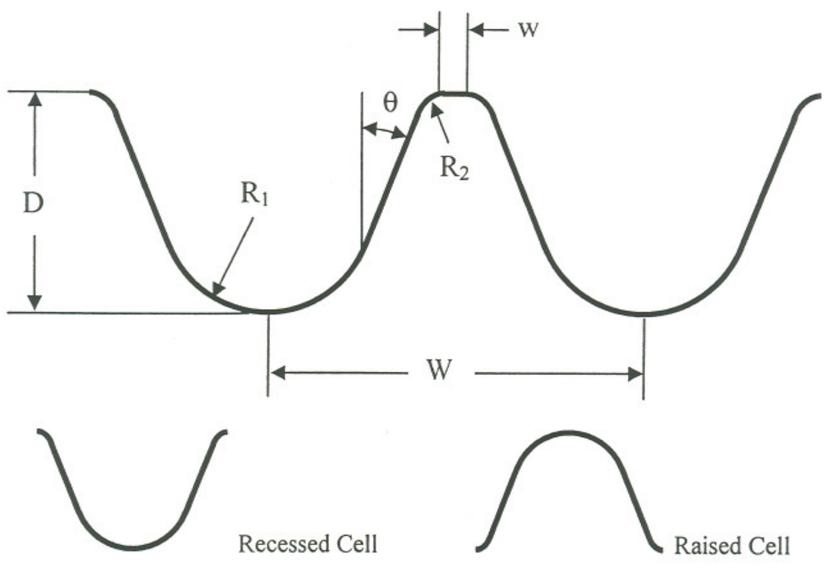
OBJECTIVES

The objective was to evaluate the survivability of marks applied with DPM processes for several critical normal aircraft landing gear part overhaul conditions. The objectives were: to evaluate mark survivability improvements for abrasive blasting processes; to evaluate mark survivability for shot peening; and to review the problem of reading a mark through protective plating and/or paint.

The objective was to develop robust marks with the mark cell shape, mark cell depth, and consequent characteristics shown in Figure 1. The objective was to find marks with the minimum depth required to survive an overhaul environment with minimum overhaul process controls. The objective was to develop the marks with several DPM processes. However, if possible, the objective was to find a single optimum mark and a single optimum DPM process for steel and aluminum landing gear parts.

The objective was to compare machine readable marks to human readable marks. The objective was to classify the root causes of mark survivability problems based on comparative criteria between the machine readable marks and the human readable marks. The comparative criteria were selected since the human readable marks are the current method for serialization. The three basic classifications were *Mark Damage*, *Reader Interface*, and *Operator Interface*.

Figure 1: Proposed Robust Mark Cell Shape



- Proposed Cell Design Applicable to Recessed Cells and Raised Cells
- D (0.004 IN to 0.008 IN): Deep Enough to Survive Processes with Reasonable Masking
- W, w: Sufficient Cell Spacing to Reduce Cell Damage
- θ: Draft Angle to Reduce Cell Damage, Cell Clogging, and Cell Stress Concentration (Kt)
- R_1, R_2: Radii to Reduce Cell Damage, Cell Clogging, and Cell Stress Concentration (Kt)
- R_1, R_2: Radii Cells / Other Cell Shapes Will Be Rounded from Blasting Processes
- Consider Parabolic Cell Design or Hyperbolic Cell Design for Optimum Reflectivity

TEST MATRIX AND DISCUSSION

Test Matrix

Symbol

Human Readable Mark: Numeric Characters
Machine Readable Mark: Data Matrix™ (22 x 22)

Data

10 Random Numeric Characters

DPM Processes

Vibropeen (Not a Machine Readable Mark)
Impression Stamp / Steel Stamp (Not a Machine Readable Mark)
Deep Laser Engrave: 0.002in. to 0.012in. Deep
Dot Peen: 0.002in. to 0.012in. Deep
Micro-Mill: 0.002in. to 0.012in. Deep

Materials

Steel, 4340, 260ksi UTS, Marked After Heat Treat
Aluminum, 7075-T73, 60ksi UTS

Surfaces

Marking Surface
Flat Surface
Smooth Surface, 125RMS

Overhaul Processes

Specification	Description
MIL-STD-1504	Abrasive Blasting
	Plastic Media per MIL-P-85891
	Glass Media per MIL-G-9954
	Garnet Media per MIL-A-21380
AMS-S-13165*	Shot Peening of Metal Parts*
MIL-STD-870	Cadmium Plating, Low Embrittlement, Electrodeposition
MIL-A-8625	Anodic Coatings for Aluminum and Aluminum Alloys
MIL-STD-7179	Finishes, Coatings, and Sealants for the Protection of Aerospace Weapons Systems
	Primer Coating, Epoxy, Waterborne per MIL-P-85582
	Top Coating, Polyurethane, High-Solids per MIL-C-85285

* Overhaul processes applied to functional surfaces only.
All other overhaul processes applied to marking surfaces.

Readers

MXi Handheld Reader: Automatic for Machine Readable Mark
Human Operators: Manual for Human Readable Mark

Test Matrix Discussion

The test matrix was selected to address several recommendations from the previous test program on the survivability machine readable marks under normal aircraft landing gear part overhaul conditions. The test matrix was selected to provide sufficient information to determine if marks applied with DPM processes on normal part marking surfaces survive normal aircraft landing gear part overhaul conditions for steel and aluminum parts. If the marks survive the selected test matrix of *Symbol*, *Data*, *DPM Processes*, *Materials*, *Surfaces*, *Overhaul Processes*, and *Readers*, then the test matrix should be expanded. If the marks do not survive the selected test matrix, then the test program should be discontinued because there is no reason to believe that the marks on steel or aluminum would survive an overhaul environment. Note that if the marks do not survive the selected test matrix, there is no reason to believe that the marks would not survive an overhaul environment for other materials, such as titanium, which are subjected to different overhaul processes than steel and aluminum.

Symbol

The Data Matrix™ symbol was selected because it is the dominant machine readable mark for DPM. The Data Matrix™ symbol may contain several hundred characters in a relatively small space.

Data

The data content of 10 characters was selected because it provides sufficient information to track a part. In addition, the data content meets the primary objective of the test program to determine if the marks will survive an overhaul environment, and the secondary objective of the test program to compare machine readable marks to human readable marks. For implementation, the data content would have to be determined by the Department of Defense or the USAF.

DPM Processes

The previous test program identified dot peen, micro-mill, and laser engrave marks for further development and testing. Steel stamp and vibropeen were included as the current USAF DPM processes. Forged marks were omitted primarily because the process is under development, but also because forged marks may offer questionable benefits over dot peen, micro mill, or deep laser engrave marks. A forged mark is expected to be a large mark and is expected to have potential problems with mark size and high data density. Finally, a concern for a forged mark is that it must be applied early on in the manufacturing process. It may provide a questionable benefit over a dot peen, micro mill, or deep laser engrave mark applied at the same early stage in the manufacturing process.

The mark depth range of 0.002in. to 0.012in. was selected because it includes the typical depth range for marks. The depth range allows comparison between the marks to assist in determining the minimum depth for mark survivability.

The marks were applied to the base materials before any protective coatings were applied. Marks must be applied to the base materials if they are to survive an overhaul environment. Note that marks may be applied to the protective coatings without damaging the protective coating or the base material. These marks may survive an operational environment. However, these marks would not survive an overhaul environment unless they penetrate into the base material. If they penetrate into the base material, the functionality of the protective coating may be compromised near the mark.

Materials

The 4340 steel and the 7075-T73 aluminum were selected for material availability. Both materials are representative of landing gear materials and both materials duplicate the strength, hardness, and surface finish of landing gear materials.

The steel and aluminum were marked after heat treatment. Applying the marks after heat treatment allows existing parts to be marked. Marking steel after heat treatment with a sufficient depth poses several technical challenges.

Surfaces
The flat surface was selected for ease of manufacture, delivery, and processing of the coupons. Marks reportedly read well on flat surfaces. Marks also reportedly read well on curved surfaces provided that the marks occupy a maximum of one third of the diameter of the curve. The smooth surface with a surface roughness of 125RMS was selected because it is a typical surface roughness for landing gear parts. Marks reportedly read well for surface roughness ranges of 64RMS to 256RMS.

Overhaul Processes
The overhaul processes were selected because they are normal aircraft landing gear part overhaul processes. Several critical overhaul processes were selected to evaluate mark survivability improvements for abrasive blasting processes; to evaluate mark survivability for shot peening; and to review the problem of reading a mark through protective plating and/or paint. The previous test program identified: the chemical stripping processes as not particularly damaging overhaul processes; the abrasive blasting processes as the most damaging overhaul processes; and the problem of reading a mark through protective plating and/or paint.

Marks are applied to marking surfaces in contrast to functional surfaces which include stress critical surfaces, wear surfaces, sealing surfaces, etc. Both a marking surface and a functional surface may be structural. A marking surface is distinguished by a comparatively large and uniform area, while a stress critical area for a functional surface is distinguished by an abrupt geometry change such as a radius. The marking surface of a landing gear part typically has a corrosion protection system consisting of protective plating and painting, while the functional surface of a landing gear part typically has a high tolerance wear resistance surface consisting of the base material or hardened plating.

A mark must survive the overhaul processes for the marking surface. However, a mark may be protected during overhaul processes that affect the functional surfaces only. For example, a mark must survive all the chemical stripping environments because both the marking and functional surfaces are exposed to the environments and simple masking is not possible. Similarly, a mark must survive the abrasive blasting preparation for the protective plating processes for a marking surface. However, it is not necessary for a mark to survive the abrasive blasting processes for hardened plating or to have hardened plating applied directly over the mark. The hardened plating for functional surfaces include: chrome plate, nickel plate, flame spray coating, and HVOF coating.

The shot peening process is more difficult to categorize for marking and functional surfaces. Shot peening introduces a compressive residual stress in the surface and is used to improve the fatigue life of a part. It is a somewhat difficult process to control, and landing gear designers typically do not rely on it for fatigue improvements. However, it is commonly used for landing gear parts. It is applied to fatigue critical areas to increase the fatigue life, and it is applied as part of the surface preparation for hardened plating to recover the fatigue debit of the plating processes.

For the test program, shot peening was considered to be applied to a functional surface. A mark should not be located in a fatigue critical area or a plating area that requires shot peening. If a part mark were shot peened, it is questionable if there is an engineering benefit because the shot peen surface coverage for the mark impressions would be questionable. It is technically possible and relatively simple to mask a mark for shot peening.

Readers
The MXi handheld reader was selected because it is an advanced reader that decodes machine readable marks. Economic and schedule constraints allowed only the MXi handheld reader to be tested.

The human operators were selected because they are the current method for reading human readable marks.

TEST PROCEDURES

Coupon Testing

1. The test matrix was developed and the testing was conducted by the ALGLE Program. The test matrix was accomplished by processing and decoding marks on several coupons. Figure 2 contains a schematic image of a coupon. The coupon drawings are contained in Appendix A. The testing focused on normal part mark locations for landing gear parts and normal aircraft landing gear part overhaul conditions.

Coupon Manufacturing

1. The coupons were manufactured by NorthWest Machining and Manufacturing (NWMM).
2. The coupon manufacturing documentation is contained in Appendix B.

Coupon Marking

1. The coupons were marked by Robotic Vision Systems Incorporated (RVSI).
2. The coupon marking documentation is contained in Appendix C.

Coupon Overhaul Process Survivability Testing

1. The coupons were processed by the ALGLE Program and OO-ALC/MANP.
   1.1 The coupons were processed at the OO-ALC Landing Gear Overhaul Facility.
   1.2 The overhaul process documentation is contained in Appendix D.
2. The decoding operations were performed by the ALGLE Program.
   2.1 The coupons were decoded in a laboratory environment.
   2.2 The decoding documentation is contained in Appendix E and Appendix F.

General Test Procedures

1. Four S1A coupons were processed as listed in Table 1.
2. Four A1A coupons were processed as listed in Table 2.
3. After each overhaul process, decoding operations were performed as listed in Table 3.

Figure 2: Coupon Schematic

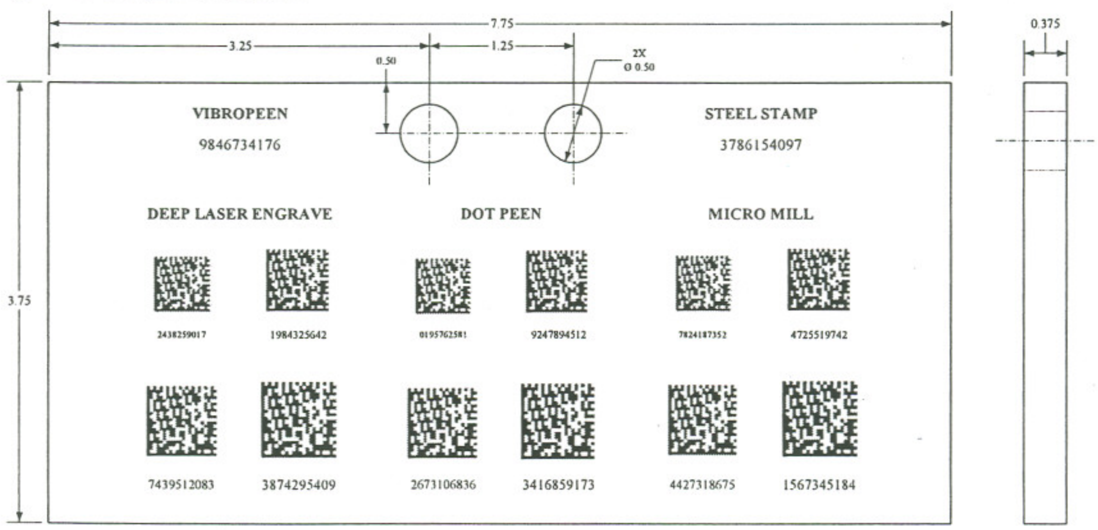


Table 1: Overhaul Processes for the Steel Coupons

Process	S1A-17	S1A-18	S1A-19	S1A-20
1. Abrasive Blast per MIL-STD-1504 – Plastic Bead per MIL-P-85891 (5X or 500% Surface Coverage / 6 Inch to 12 Inch Distance)	Yes	Yes	Yes	Yes
2. Abrasive Blast per MIL-STD-1504 – Glass Bead per MIL-G-9954 (5X or 500% Surface Coverage / 6 Inch to 12 Inch Distance)	Yes	Yes	Yes	Yes
3. Abrasive Blast per MIL-STD-1504 – Garnet per MIL-A-21380 (5X or 500% Surface Coverage / 6 Inch to 12 Inch Distance)	Yes	Yes	Yes	Yes
4. Shot Peen per AMS-S-13165, Intensity 0.010A to 0.014A, Shot S-230 (5X or 500% Surface Coverage)	Yes Mask Marks	Yes	No	No
5. Cadmium Plate per MIL-STD-870, Type II, Class 1 Within 4 Hours After Cadmium Plate Bake For 24 Hours at 375°F	No	No	Yes	Yes
6. Paint per MIL-STD-7179 One Coat Primer per MIL-P-85582 Type I, Class 2 / Two Top Coats per MIL-C-85285, Type I	No	No	No	Yes
7. Clean	Scotch Pad	Scotch Pad	Dry Cloth	Dry Cloth

Table 2: Overhaul Processes for the Aluminum Coupons

Process	A1A-17	A1A-18	A1A-19	A1A-20
1. Abrasive Blast per MIL-STD-1504 – Plastic Bead per MIL-P-85891 (5X or 500% Surface Coverage / 6 Inch to 12 Inch Distance)	Yes	Yes	Yes	Yes
2. Abrasive Blast per MIL-STD-1504 – Glass Bead per MIL-G-9954 (1X or 100% Surface Coverage / 6 Inch to 12 Inch Distance)	Yes	Yes	Yes	Yes
3. Shot Peen per AMS-S-13165, Intensity 0.010A to 0.014A, Shot S-230 (5X or 500% Surface Coverage)	Yes Mask Marks	Yes	No	No
4. Anodize per MIL-STD-8625, Type II, Class 1	No	No	Yes	Yes
5. Paint per MIL-STD-7179 One Coat Primer per MIL-P-85582 Type I, Class 2 / Two Top Coats per MIL-C-85285, Type I	No	No	No	Yes
6. Clean	Scotch Pad	Scotch Pad	Dry Cloth	Dry Cloth

Table 3: Decoding Operations

1. Perform the decoding operations with the operator, the MXi handheld reader, and the database.
   1.1 Successful Decode: Mark decodes with 1/6 to 6/6 attempts.
   1.2 Unsuccessful Decode: Mark does not decode with 0/6 attempts.
   The 6 attempts are competed with 1 operator decoding the mark 6 times.
2. Perform the decoding operations with the operator and the database.
   2.1 Successful Decode: Mark data correctly entered into a database with 6/6 attempts.
   2.2 Unsuccessful Decode: Mark data incorrectly entered into a database with 0/6 to 5/6 attempts.
   The 6 attempts are completed with 3 operators each entering the mark data 2 times.

RESULTS AND DISCUSSION

Results

All the test results are presented in terms of the coupon part numbers S1A and A1A which contain basic information about the material and when the material was marked. Coupon S1A was 4340 steel (S) that was marked after (A) heat treating to 260 ksi UTS. Coupon A1A was 7075-T73 aluminum (A) that was marked after (A) heat treating. Detailed test results are contained in Appendix E and Appendix F.

A summary of the test results is contained in Figure 3 through Figure 5 and Table 4 through Table 7. Figure 3 contains summary test results for mark survivability of all the marks on coupons S1A and A1A. Figure 4 and Figure 5 contain summary test results for the individual coupons. Table 4 and Table 5 contain images of the marks before and after processing. Table 6 and Table 7 contain test results for the depth of the mark cells as measured with a dial depth gage.

Definition of Mark Survivability

For the test program, two methods were used to assess mark survivability through the overhaul processes. For the machine readable marks, an automatic quantitative survivability measurement was conducted with one operator, an MXi handheld reader, a computer, and an Excel database. For the human readable marks, a manual quantitative survivability measurement was conducted with three operators, a computer, a computer keyboard, and an Excel database. The MXi handheld reader measurement would be useful for an operator to decode the mark in an overhaul environment. The manual measurement would also be useful for an operator to decode the mark in an overhaul environment. Quantitative survivability measurements were not conducted with any fixed station readers. A fixed station reader measurement may be useful for an operator monitoring mark quality during the DPM process or for a mishap investigator who must decode the mark. For daily use in a landing gear overhaul environment a fixed station reader would not be appropriate.

All the decoding with the MXi handheld reader was conducted in a laboratory environment with ambient lighting by one well educated and well trained operator. All the manual decoding was conducted in a laboratory environment with ambient lighting by three well educated and well trained operators.

For the test program, the definition of machine readable mark survivability was the ability to successfully decode the mark with an MXi handheld reader within 6 attempts. For the test program the definition of human readable mark survivability was the ability for three operators to independently and successfully enter the mark data into an Excel database two times correctly. With the definitions, the mark survivability could change with the operator, the environment, or with an improved handheld reader.

For the test program, the definition of lifetime traceability was the ability to successfully decode the mark after each overhaul process. With this definition, the lifetime traceability could change with the operator, the environment, or with an improved handheld reader.

Root Causes of Mark Survivability Problems

For the test program, three classifications for the root causes of mark survivability problems were considered. The classifications were based on comparative criteria between the machine readable marks and the human readable marks. The comparative criteria were selected since the human readable marks are the current method for serialization.

The first classification was *Mark Damage* which indicated that the mark was damaged and that the problem was with the mark or the overhaul process. *Mark Damage* was considered the root cause if neither the human readable marks nor the machine readable marks decoded. The second classification was *Reader Interface* for the machine readable marks which indicated that the mark was not damaged and that the problem was with the machine readable symbol and/or the reader. *Reader Interface* was considered the root cause if the majority of the human readable marks decoded and the machine readable marks did not decode. The third classification was *Operator Interface* for the human readable marks which indicated that the mark was not damaged and that the problem was with the human readable characters and/or the manual data entry.

Operator Interface was considered the root cause if the majority of the human readable marks decoded and the majority of the machine readable marks decoded.

Mark Survivability after Different Overhaul Processes

The test results for steel and aluminum marked with deep laser engrave, dot peen, and micro mill after heat treatment are contained in Figure 3 through Figure 5. The test data demonstrates that for lifetime traceability the human readable marks outperform the machine readable marks. The test data demonstrates that an operator is able to discern a mark better than a reader when the mark is obscured by a discolored surface, plating, or painting. After overhaul processes where the machine readable marks perform reliably, they outperform the human readable marks by approximately 5%. However, after the overhaul processes where the machine readable marks do not perform reliably, they are outperformed by the human readable marks by approximately 75%. The average decoding time for the machine readable marks was 3s per mark, and the average decoding time for the human readable marks was 10s per mark. For a mark with 10 characters, the machine readable mark offered only a slight improvement in time efficiency over the human readable mark. Finally, the survivability of the machine readable marks and the human readable marks is attributed to the mark cell shape and the mark depth.

The test results for steel are contained in Figure 4. The test data demonstrates that the majority of the machine readable marks survive all the processes except cadmium plating and painting. The test data demonstrates that the majority of the human readable marks survive all the processes. The test data demonstrates that the marks survive abrasive blasting processes that are applied to marking surfaces. The test data demonstrates that the marks survive shot peening. However, mark damage in the form of a disrupted surface was present after shot peening, but when the marks were masked the mark damage was not present. The root cause for the survivability problems for the marks with an initial depth of 0.000in. to 0.002in. was classified as *Mark Damage*. The root cause for the survivability problems for the remaining machine readable marks after cadmium plating and painting was classified as *Reader Interface*. The root cause for the survivability problems for the remaining human readable marks was classified as *Operator Interface*.

The test results for aluminum are contained in Figure 5. The test data demonstrates that the majority of the machine readable marks survive all the processes except shot peening and painting. The test data demonstrates that the majority of the human readable marks survive all the processes except shot peening. The test data demonstrates that the marks survive abrasive blasting processes that are applied to marking surfaces. The test data demonstrates that the marks do not survive shot peening. Mark damage in the form of a highly disrupted surface was present after shot peening, but when the marks were masked the mark damage was not present. One option to maintain mark survivability for shot peening is a process control to mask a mark for shot peening. Another option may be to pursue a significantly deeper mark. The test data demonstrates that a significantly deeper mark would be required, since the 0.012in. deep marks did not survive shot peening. In the previous test program, a 0.026in. deep mark was highly damaged. Pursuing larger and deeper marks would limit the practicality of the mark by limiting the amount of parts that could be marked and would also reduce the mark benefits of mark size and high data density. The root cause for the survivability problems for the marks with an initial depth of 0.000in. to 0.002in. was classified as *Mark Damage*. The root cause for the survivability problems for the marks after shot peening was classified as *Mark Damage*. The root cause for the survivability problems for the remaining machine readable marks after painting was classified as *Reader Interface*. The root cause for the survivability problems for the remaining human readable marks was classified as *Operator Interface*.

Current DPM Processes and New DPM Processes

The current DPM processes of vibropeening and steel stamping human readable marks were compared to the new DPM processes of deep laser engraving, dot peening, and micro milling human readable marks. The only conclusive test result was that steel stamping steel after heat treatment is not a reliable marking practice. This was known before the test program, but steel stamping was included to provide a comparison. The test data provided a slight indication that the new DPM processes would outperform the current processes in the sense that the operators concurred that the new DPM processes provided standardized characters with improved character clarity. However, the plots in Appendix E do not provide conclusive test results that the new DPM processes outperformed the current DPM processes. There was limited data for the comparison, and additional data would be required for conclusive test results.

Mark Cell Shape and Mark Depth

The mark cells had radii, draft angles, and spacing to reduce cell damage and cell clogging. The mark cells from the different DPM processes were examined under an optical microscope. For the different DPM processes, the mark cells all had variations of radii, draft angles, and spacing. The test data indicates that mark cells with radii, draft angles, and spacing provide a robust shape that performs well for variations of radii, draft angles, and spacing.

The test results for mark cell depths are contained in Table 6 and Table 7. The mark cells had depths ranging from 0.000in. to 0.012in. The test data demonstrates that: marks with depths less than 0.002in. did not perform well and frequently had problems for both human readable and machine readable marks with a root cause classification of *Mark Damage*; marks with depths greater than 0.003in. performed well for the majority of the conditions. However, the dot peen marks and micro mill marks with greater depth were observed to have some problems with machine reading. Also, deeper marks begin to encounter problems with mark size and high data density. The test results in Figure 3 through Figure 5 demonstrate these trends where the survivability for marks between 0.003in to 0.009in. is greater than or equal to the survivability for marks between 0.000in. and 0.012in. The test data indicates that the minimum depth for mark survivability with reasonable process controls is 0.003in. The test data also indicates that a reasonable depth range for mark survivability is 0.003in to 0.009in.

Optimum DPM Process

The test results for the steel and aluminum are somewhat confounded since with reasonable process controls all the marks performed reasonably well. The test results are also somewhat confounded since the machine readable marks and the human readable marks performed differently. The test data indicates that deep laser engrave marks were the top performing machine readable marks. The test data indicates that micro mill marks were the top performing human readable marks. The test data does not conclusively identify an optimum marking process. It indicates that mark cells with radii, draft angles, and spacing provide a robust shape. Additional evaluations, such as a DPM process evaluation or a mark and materials characterization evaluation would be required to identify an optimum DPM process.

A DPM process evaluation is beyond the scope of the current test program. However, there are several preliminary indications about the DPM processes that would assist in developing an evaluation to identify an optimum DPM process. The preliminary indications are that deep laser engraving would provide an optimum DPM process based on manufacturing considerations. Deep laser engraving: conformed to the mark depth and mark size requirements for steel and aluminum; is controllable and flexible in terms of mark depth and mark size; is expected to be able to mark curved surfaces; and is expected to require minimal fixturing. Deep laser engraving is expected to require a confined laser safe space. Dot peening and micro milling: did not conform to the mark depth or mark size requirements for steel on a flat surface; are not expected to mark curved surfaces on high strength steel due to problems with the marking tool shifting; and are expected to require significant fixturing with approximately one fixture per part.

A mark and materials characterization evaluation is beyond the scope of the current test program. However, there are several preliminary indications about the marks that would assist in developing an optimum DPM process. Dot peen marks are considered qualified for safety critical parts. Deep laser engrave marks have a shallow heat affected zone which is unacceptable for safety critical parts. There is a preliminary indication that the shallow heat affected zone may be removed by glass blasting for aluminum or by garnet blasting for steel. Micro mill marks do not have a shallow heat affected zone. However, machining high strength steel is usually avoided, and DPM process controls to avoid machining burns for high strength steel would be required.

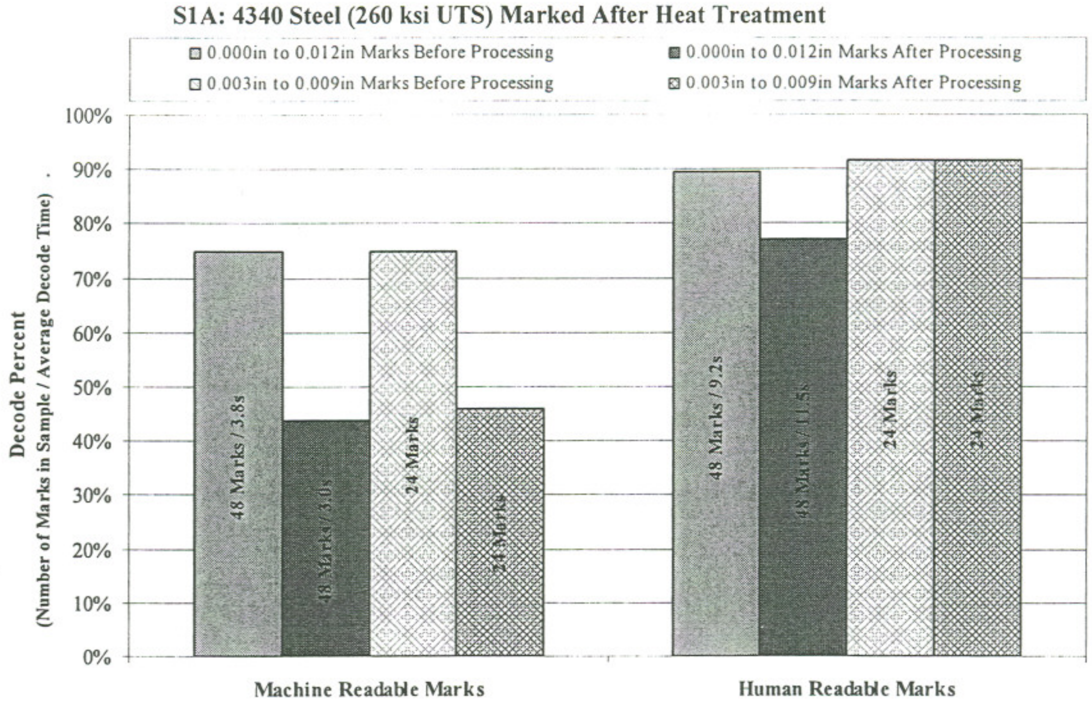
Mark and Reader Improvements

The were several improvements in the marks in the current test program over the marks in the previous test program. No mark cell clogging due to the abrasive blast media was observed. Very minor clogging due to the mask media for shot peening was observed. The clogging was limited to a few cells on a micro mill mark and it was cleaned in approximately 10s. Uniform cadmium plating over all the mark cells was observed. Uniform anodize over all the mark cells was observed. For the deep laser engrave, the anodize was uniform but darker in appearance. Uniform primer coating over all the mark cells was observed. Relatively uniform paint coating over most of the mark cells was observed. The deep laser engrave marks had some cells with no paint coating on the walls, and the primer coating was exposed.

There were no improvements in mark enhancements, such as backfilling, for the current test program over mark enhancements in the previous test program. For steel, mark enhancements after cadmium plating and painting could significantly improve the survivability of the marks. For aluminum, mark enhancements after painting could significantly improve the survivability of the marks. A successful mark enhancement would maintain the corrosion protection system for the marking surface. This is particularly important for landing gear parts where corrosion is a serious problem.

There were no improvements in the reader for the current test program over the reader in the previous test program. Economic and schedule constraints allowed only the MXi handheld reader to be tested. No other optical readers and no zero contrast readers or read through protective coating readers were reviewed as part of the current test program. Despite the development and improvements of zero contrast technologies, the optical imaging remains the most advanced and best performing technology for most applications and environments. The test data indicates that a non-contact method of detecting depth change would be the best zero contrast technology. It may reduce cleaning before decoding and it may image depth changes through protective coatings.

Figure 3: Mark Survivability / Mark Decode Percent
Marks Applied with Deep Laser Engrave, Dot Peen, and Micro Mill DPM Processes



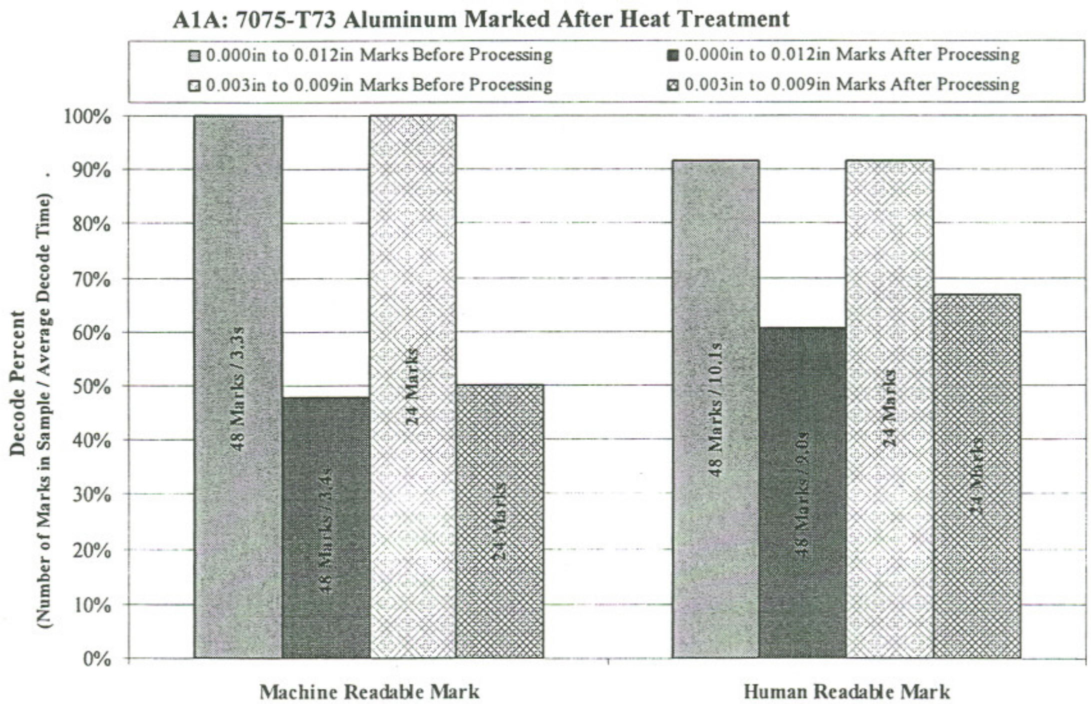
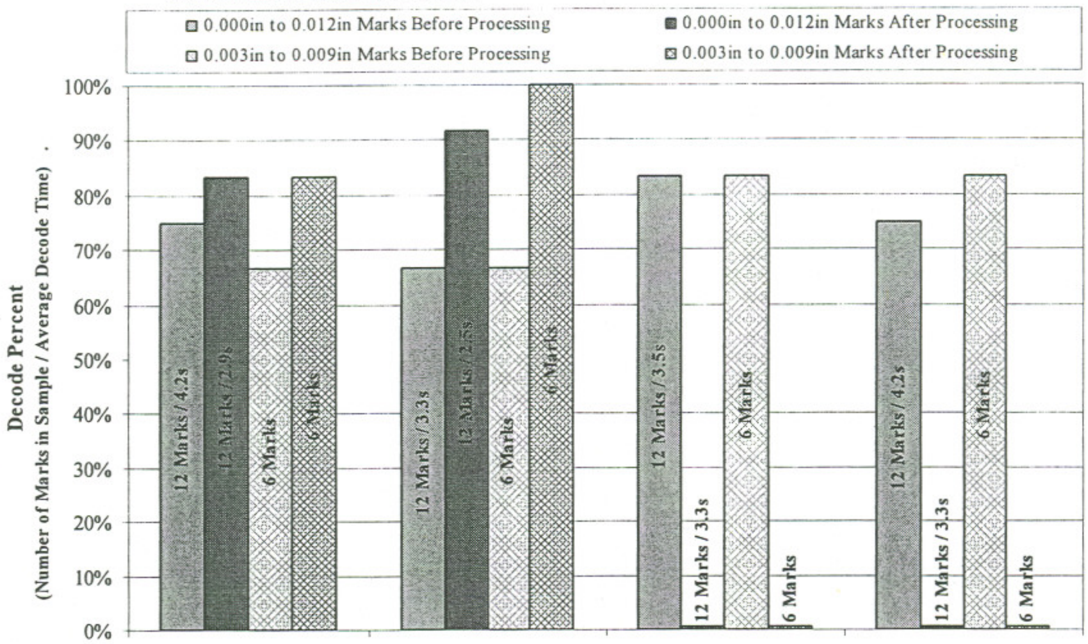


Figure 4: Mark Survivability / Mark Decode Percent
Marks Applied with Deep Laser Engrave, Dot Peen, and Micro Mill DPM Processes
S1A: 4340 Steel (260 ksi UTS) Marked After Heat Treatment

A. Machine Readable Marks



B. Human Readable Marks

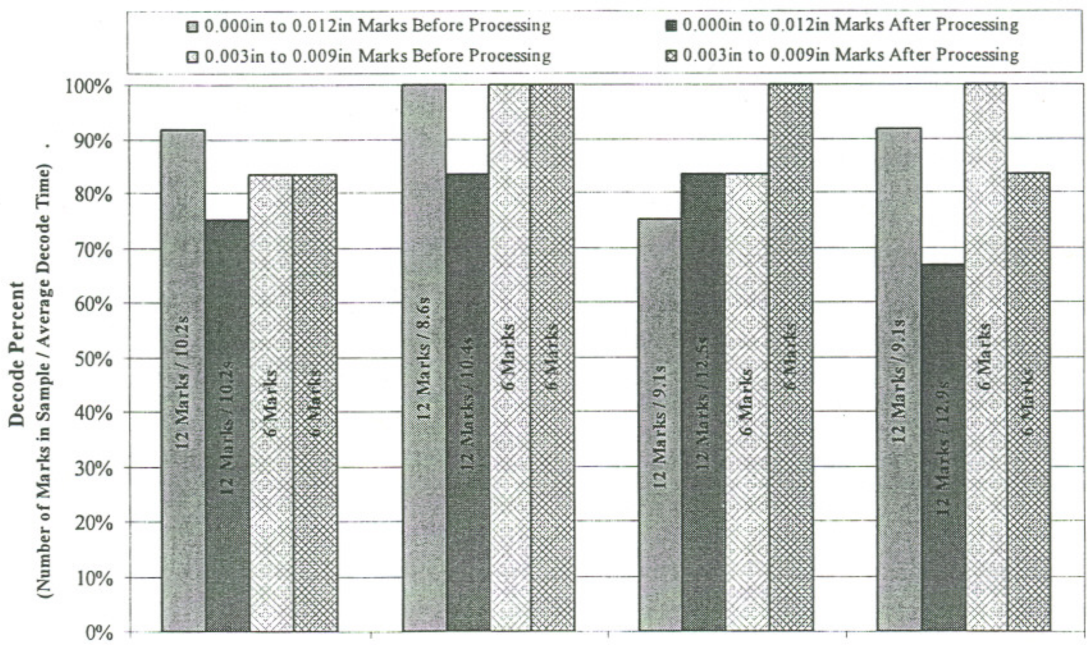
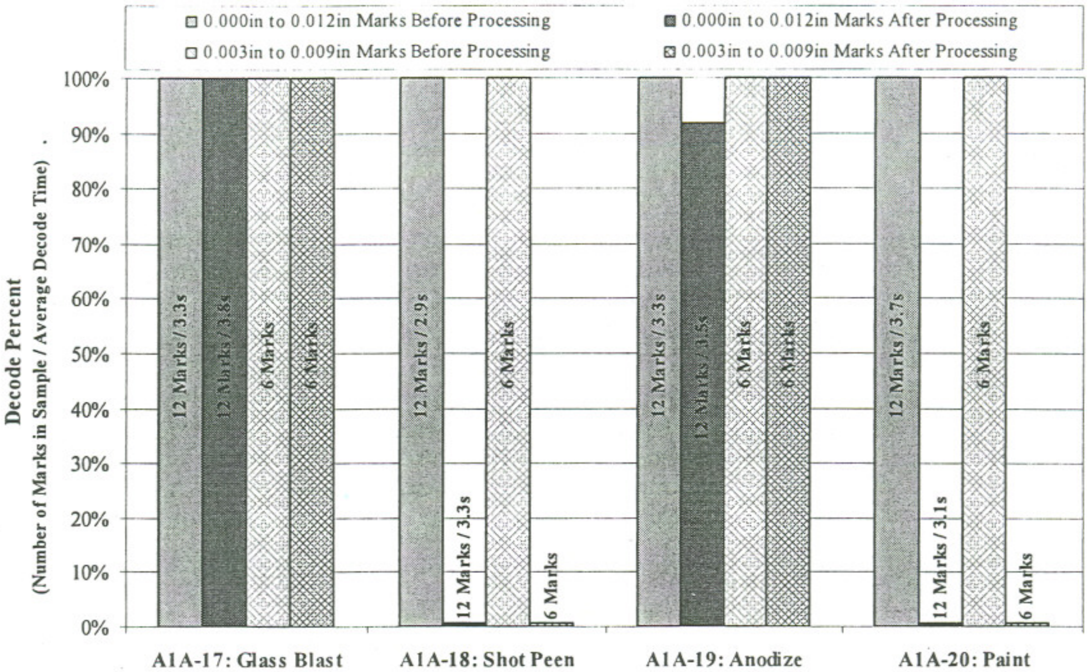


Figure 5: Mark Survivability / Mark Decode Percent
Marks Applied with Deep Laser Engrave, Dot Peen, and Micro Mill DPM Processes
A1A: 7075-T73 Aluminum Marked After Heat Treatment

A. Machine Readable Marks



B. Human Readable Marks

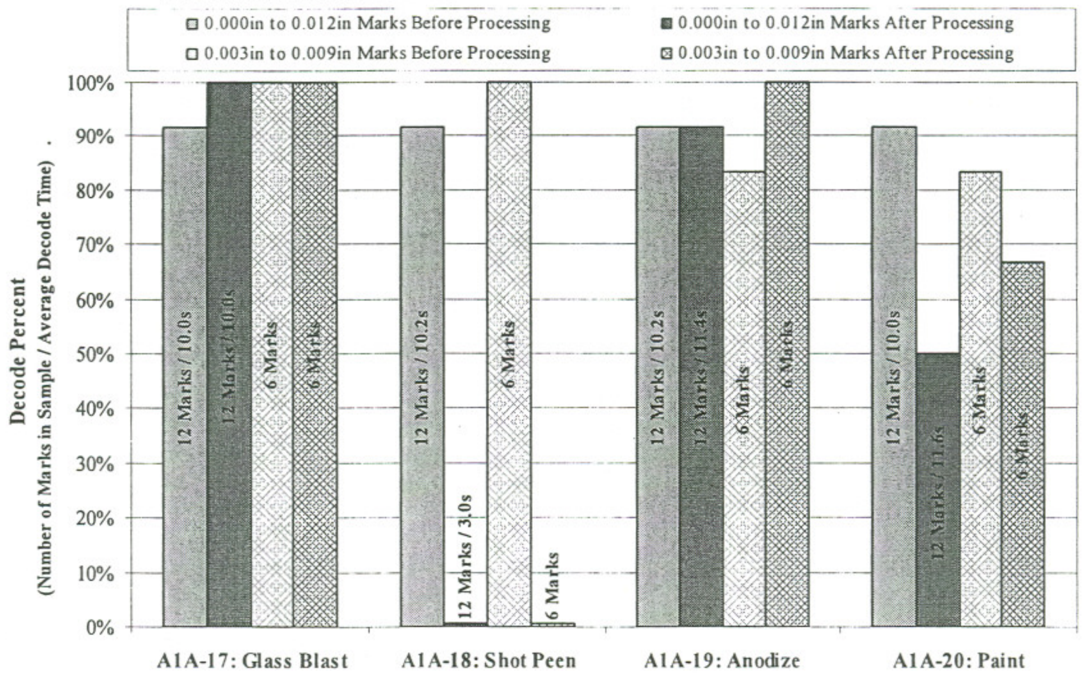


Table 4: Images of Initial Mark and Final Mark After Processes for Coupons S1A*
S1A: 4340 Steel (260 ksi UTS) Marked After Heat Treatment

DPM Process (Average Depth)	S1A-17 Before Processes	S1A-17 After Garnet Blast	S1A-18 After Shot Peen	S1A-19 After Cadmium Plate	S1A-20 After Paint
Vibropeen (0.002in)					
Steel Stamp (0.001in)					
Deep Laser Engrave (0.009in)					
Dot Peen (0.006in)					
Micro Mill (0.007in)					

Table 5: Images of Initial Mark and Final Mark After Processes for Coupons A1A *
A1A: 7075-T73 Aluminum Marked After Heat Treatment

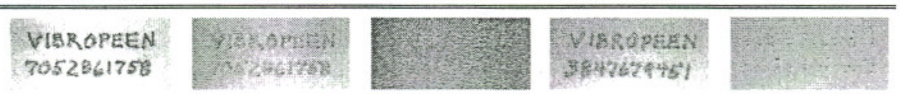
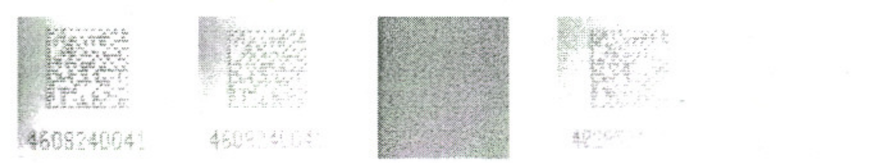
DPM Process (Average Depth)	A1A-17 Before Processes	A1A-17 After Glass Blast	A1A-18 After Shot Peen	A1A-19 After Anodize	A1A-20 After Paint
Vibropeen (0.006in)					
Steel Stamp (0.009in)					
Deep Laser Engrave (0.007in)					
Dot Peen (0.007in)					
Micro Mill (0.007in)					

Table 6: Coupon S1A: Mark Cell Depth Before and After Processing*
Average Depth in Inches Based on 3 Dial Gage Measurements

DPM Process	Before				After			
	Mark 1	Mark 2	Mark 3	Mark 4	Mark 1	Mark 2	Mark 3	Mark 4
Vibropeen	0.002	NA	NA	NA	0.002	NA	NA	NA
Steel Stamp	0.001	NA	NA	NA	0.000	NA	NA	NA
Deep Laser Engrave	0.003	0.004	0.009	0.013	0.002	0.003	0.008	0.012
Dot Peen	0.001	0.002	0.004	0.006	0.000	0.001	0.003	0.005
Micro Mill	0.001	0.002	0.007	0.011	0.000	0.002	0.006	0.010

Table 7: Coupon A1A: Mark Cell Depth Before and After Processing*
Average Depth in Inches Based on 3 Dial Gage Measurements

DPM Process	Before				After			
	Mark 1	Mark 2	Mark 3	Mark 4	Mark 1	Mark 2	Mark 3	Mark 4
Vibropeen	0.006	NA	NA	NA	0.003	NA	NA	NA
Steel Stamp	0.009	NA	NA	NA	0.006	NA	NA	NA
Deep Laser Engrave	0.002	0.003	0.007	0.012	0.001	0.002	0.005	0.008
Dot Peen	0.001	0.003	0.007	0.011	0.000	0.001	0.003	0.007
Micro Mill	0.002	0.003	0.007	0.012	0.001	0.002	0.005	0.009

*A depth of 0.000in. indicates that no depth measurement could be taken.

CONCLUSIONS

The test program was conducted to evaluate the survivability of improved machine readable and human readable marks applied with direct part marking processes for normal aircraft landing gear part overhaul conditions. Specifically, the test program was to determine if the marks provide lifetime traceability for landing gear parts by surviving normal aircraft landing gear part overhaul conditions.

The test data demonstrates that for lifetime traceability the human readable marks outperform the machine readable marks. The test data demonstrates that the marks do not provide a system for complete lifetime traceability. However, no single manual or automatic identification and tracking technology is known to provide the level of lifetime traceability that is being considered. For lifetime traceability, multiple tracking technologies must be employed.

The test data demonstrates that the marks may provide improved overhaul to overhaul traceability, and improved traceability in an overhaul environment. The improved traceability could be used to better track the number of overhauls for a part or to audit part traceability at critical points within an overhaul environment. The improved traceability could assist with better part data for mishap investigations.

The test data demonstrates that the deep laser engrave, dot peen, and micro mill marks will survive the overhaul processes with reasonable process controls. The test data for steel demonstrates that the majority of the machine readable marks survive all the processes except cadmium plating and painting, and that the majority of the human readable marks survive all the processes. The test data for aluminum demonstrates that the majority of the machine readable marks survive all the processes except shot peening and painting, and that the majority of the human readable marks survive all the processes except shot peening. The root cause of the mark survivability problems for cadmium plating and painting was *Reader Interface* which indicated that the mark was not damaged and that the problem was with the machine readable symbol and/or the reader. The root cause of the mark survivability problems for shot peening was *Mark Damage* which indicated that the mark was damaged and that the problem was with the mark or the overhaul process.

The test data indicates that mark cells with radii, draft angles, and spacing provide a robust shape that performs well for variations of radii, draft angles, and spacing. The test data indicates that the minimum depth for mark survivability with reasonable process controls is 0.003in. The test data also indicates that a sufficient depth range for mark survivability is 0.003in to 0.009in.

The test data indicates that processing requirements define the shape of the mark. While the mark cell shape may be further optimized, significant improvements over a mark cell shape with radii, draft angles, and spacing are not expected. Improvements in the mark and reader interface may be expected. The improvements could be with the mark symbology. For example, a new version of the Data Matrix™ symbol that has an equal number of light and dark cells could reduce the dependency to detect an absolute contrast for reader decoding. This benefit could apply to optical readers and to zero contrast readers. The improvements could be with the reader. For example, better optical imagers, zero contrast imagers, or improved software algorithms that are developed for round cells could improve reading. The research and development of readers is continuing and improvements in reading may be expected.

RECOMMENDATIONS

Based on the test data, it is recommended to pursue the development and implementation of a serial number tracking system with labels as the primary interface and marks applied with DPM processes as the secondary interface. Both the labels and the parts should include machine readable marks and human readable marks. The machine readable mark would be used as the primary mark for automatically interfacing with the part. The human readable mark would be used as the secondary mark for manually interfacing with the part when the machine readable mark does not work. Note that if there is limited space on a label or a part, then the human readable mark should be the primary mark, since the test data demonstrates that the human readable mark provides better traceability. When the part is on an aircraft, the label could be a stencil painted mark with a clear protective top coat. When a part is off an aircraft, the label could be adhered to the part or tethered to the part. When the part is off an aircraft for repair and overhaul, and the paint and plating are removed, the marks applied with DPM processes should be used to audit part traceability.

The recommended development and implementation of marks applied with DPM processes should sequentially conduct a return on investment evaluation, a DPM process evaluation, a mark and materials characterization evaluation, and an implementation evaluation before final implementation. During the evaluations, the development of marks applied with DPM processes could be terminated if economic or technical problems are encountered. If the economic or technical problems are solved and if readers or mark enhancements are developed, the secondary mark applied with DPM processes could gradually be phased in to replace the primary label. There are several considerations for the evaluations:

A return on investment analysis would assist in determining how resources should be allocated in developing a serial number tracking system with labels as the primary interface or marks applied with DPM processes as the secondary interface. The return on investment analysis would assist in determining the amount of resources to be allocated in identifying and solving technical problems with marks applied with DPM processes.

A DPM process evaluation would identify advantages and disadvantages of the various DPM processes, and it would potentially identify an optimum DPM process. The preliminary indication is that deep laser engraving would provide an optimum DPM process based on manufacturing considerations, and that dot peening and micro milling are expected to have problems with marking curved surfaces and fixturing. A basic DPM process evaluation could consist of marking curved surfaces of high strength steel. Marking and testing simple curved surfaces could identify critical issues with the DPM processes just as marking and testing simple flat surfaces identified several critical issues with the marks.

A mark and materials characterization would identify problematic mark features, and it would be required to qualify a new marking process. A complete mark and materials characterization would include microscopy, fatigue, and stress corrosion cracking evaluations. For example, deep laser engrave marks have a shallow heat affected zone which is unacceptable for safety critical parts. There is a preliminary indication that the shallow heat affected zone may be removed by glass blasting for aluminum or by garnet blasting for steel. A mark and materials characterization would be required to qualify a deep laser engrave mark.

An implementation evaluation would be to focus on actual parts and include all the complexity of using a mark on the part in the actual usage environment. For an overhaul environment, an implementation evaluation could focus on marking and tracking a select number of parts. An implementation evaluation in an overhaul environment could be conducted with condemned parts if there are questions about the materials characterization. An implementation evaluation in a field environment would require completely qualified marks. The focus of the implementation evaluation would be to confirm previous laboratory test results and to determine if the laboratory testing for mark survivability correlated with actual conditions or omitted any critical processes. For example, all of the laboratory tests that have been conducted with coupons use flat surfaces and the decoding is done by a well trained operator in a laboratory environment. The reliability of the machine readable mark and the human readable mark may not be as high on an actual part with a more complicated geometry or in an actual overhaul environment.

For development and implementation of marks applied with DPM processes, based on the test data, there are several recommendations regarding the mark cell shape, auditing part traceability, and overhaul process controls, for normal aircraft landing gear part overhaul conditions:

The mark cells should include radii, draft angles, and spacing with a mark depth range from 0.003in. to 0.009in. for mark survivability with reasonable process controls.

The marks would be used to audit part traceability in a normal landing gear part overhaul process after *Paint Stripping*, after *Evaluation and Inspection (E&I)*, and before *Plating and Painting*.

Note that in the event that a machine readable mark did not decode at critical process points, the operator would be required to manually enter the serial number into the data base. If it is a critical part, the operator could be required to enter the serial number into the database twice with character obfuscation to ensure that the serial number is entered from the part correctly. In more critical applications, two operators could be required to independently enter the serial number into the database to ensure that the serial number is entered from the part correctly.

Note that corrosion is a serious problem for landing gear, and it is not recommended to disturb the corrosion protection system of cadmium plating, anodizing, priming, and painting to decode the mark. It is recommended to use the mark as the secondary traceability feature until the problems with plating and painting can be further researched and solved.

The marks would require several overhaul process controls. The overhaul process controls would be best implemented through operator training: to recognize and protect a mark during processing; and to decode a mark. The training to recognize and protect a mark would at a minimum include training for: disassembly and nick and burr operators to recognize a mark and not remove a mark with grinding wheels; masking a mark for shot peening; and masking a mark for grit blasting. Training to decode a mark would at a minimum consist of locating the mark, cleaning the mark area, and gaining familiarity with the reader.

For development and implementation of marks applied with DPM processes, based on the test data, it is recommended to pursue the development and testing of readers and mark enhancements with performance requirements that encourage reader competition. Significantly improved readers or mark enhancements could solve the problems of painting and plating. Several reader companies have developed readers that may be well suited for decoding the marks. Performance requirements and reader competition are important since they may enable the Department of Defense or the USAF to successfully require machine readable marks within the constraints of the current logistics and procurement policies.

Future mark and reader development and testing should focus on a handheld reader that is suitable for an overhaul environment. It is recommended to maintain the primary guidelines that: the mark(s) and reader(s) must provide lifetime traceability for landing gear parts; the machine readable mark(s) and reader(s) must compete with the human readable mark(s) and operator(s) through increased traceability and efficiency; and the mark(s) and reader(s) must function as an automatic identification and tracking technology to assist an operator in collecting data directly from landing gear parts in an overhaul environment.

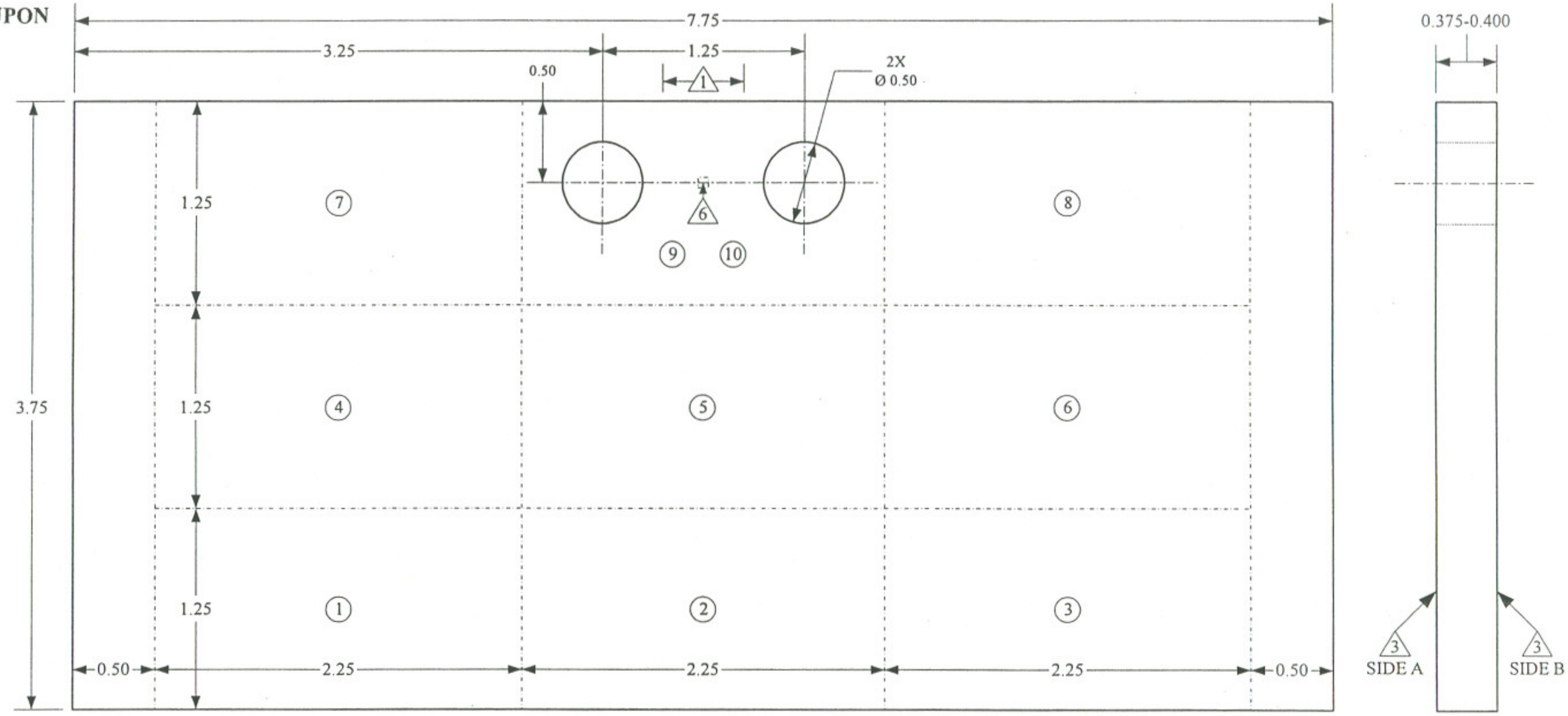
APPENDIX A
COUPON DRAWINGS

COUPON S1A

COUPON S1A REVISION D HISTORY

New: Unmarked Coupon
A: Unmarked Coupon: Drawing Configuration Change
B: Unmarked Coupon: Material Change
C: Marked Coupon: S1A-01 to S1A-16
D: Marked Coupon: S1A-17 to S1A-20

COUPON



NOTES

1. SERIALIZE THE COUPONS S1A-01 TO S1A-22 ON TOP EDGE AT NOTED LOCATION USING 0.25 IMPRESSION STAMP, 0.004-0.008 DEEP
2. HEAT TREAT AND PROCESS TO 260-280 KSI ULTIMATE TENSILE STRENGTH PER AMS-H-6875, MAXIMUM ALLOWABLE DECARBURIZATION 0.003
3. 0.025 125/64 M BEFORE 2, 125/64 M AFTER 2
4. BREAK ALL SHARP EDGES 0.005-0.015
5. FLUORESCENT MAGNETIC PARTICLE INSPECT PER ASTM E1444
6. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM ROCKWELL HARDNESS C TEST PER ASTM A370 AT NOTED LOCATION
7. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM SURFACE ROUGHNESS MEASUREMENT PER ASME B46.1

1 – 10
- i) FOR COUPONS S1A-01 TO S1A-04: MARK SIDE A WITH DATA MATRIX™ SYMBOLS PER TABLE I REQUIREMENTS
- ii) FOR COUPONS S1A-05 TO S1A-16: MARK SIDE A WITH DATA MATRIX™ SYMBOLS PER TABLE II REQUIREMENTS
- iii) FOR COUPONS S1A-17 TO S1A-20: MARK SIDE A WITH DATA MATRIX™ SYMBOLS PER TABLE III REQUIREMENTS

ALGLE PROGRAM	TITLE COUPON	DRAWING NUMBER S1A	REVISION D	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 4340 PER AMS 6415	DATE 2/28/03	SHEET 1 OF 4	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

TABLE I: DATA MATRIX™ OPTIMIZATION

(1) – (10) i) AT LEAST ONE COUPON MUST CONTAIN THE MINIMUM NUMBER OF MARKS
ii) FOR THE MINIMUM NUMBER OF MARKS, USE DIFFERENT DPM PROCESS CONTROLS

(1) DOT PEEN A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

(2) LASERSHOT™ PEEN A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

(3) MICRO-MILL A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

(4) LASER BOND A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

(5) LASER ETCH A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

(6) GAS ASSIST LASER ETCH (GALE) A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

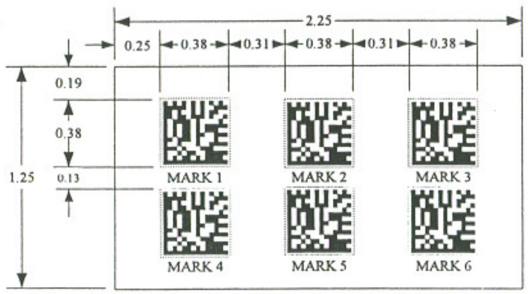
(7) LASER ENGRAVE A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

(8) LASER INDUCE SURFACE IMPROVEMENT (LISI) A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

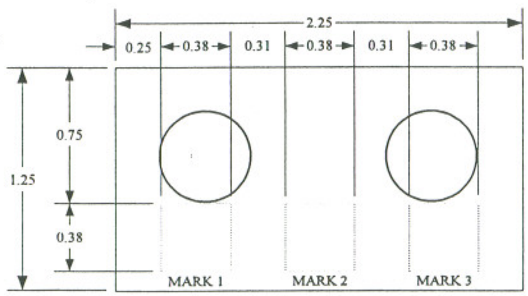
(9) VIBRA-ETCH A MINIMUM OF 3 MARKS IN DETAIL I.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)

(10) IMPRESSION STAMP A MINIMUM OF 3 MARKS IN DETAIL I.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)

DETAIL I.A*



DETAIL I.B*



	MARK DATA
(1)	XXXXXXXXXX
(2)	XXXXXXXXXX
(3)	XXXXXXXXXX
(4)	XXXXXXXXXX
(5)	XXXXXXXXXX
(6)	XXXXXXXXXX
(7)	XXXXXXXXXX
(8)	XXXXXXXXXX
(9)	ALPHANUMERIC CHARACTER
(10)	ALPHANUMERIC CHARACTER

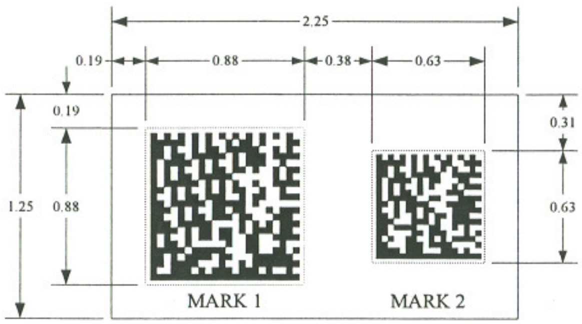
*DIMENSIONS INDICATE THE MAXIMUM ALLOWABLE AREA FOR MARKING

ALGLE PROGRAM	TITLE COUPON	DRAWING NUMBER S1A	REVISION D	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 4340 PER AMS 6415	DATE 2/28/03	SHEET 2 OF 4	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

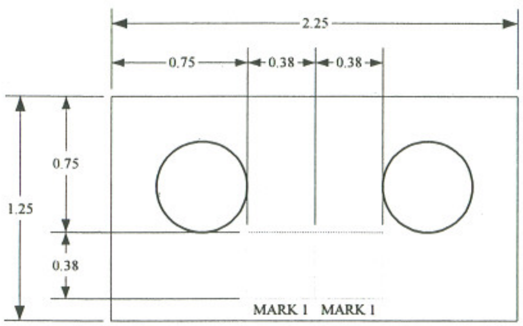
TABLE II: DATA MATRIX™ REQUIREMENTS

1. DOT PEEN MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
2. LASERSHOT™ PEEN MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
3. MICRO-MILL MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027), 0.024-0.032 DEEP
4. LASER BOND MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027)
5. LASER ETCH MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027)
6. GAS ASSIST LASER ETCH (GALE) MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027)
7. LASER ENGRAVE MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
8. LASER INDUCE SURFACE IMPROVEMENT (LISI) MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027)
9. VIBRA-ETCH MARK IN DETAIL II.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)
10. IMPRESSION STAMP MARK IN DETAIL II.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)

DETAIL II.A*



DETAIL II.B*



	MARK DATA	
	MARK 1 DATA	MARK 2 DATA
1	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX1	XXXXXXXXXXXXXXXXXXX1
2	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX2	XXXXXXXXXXXXXXXXXXX2
3	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX3	XXXXXXXXXXXXXXXXXXX3
4	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX4	XXXXXXXXXXXXXXXXXXX4
5	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX5	XXXXXXXXXXXXXXXXXXX5
6	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX6	XXXXXXXXXXXXXXXXXXX6
7	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX7	XXXXXXXXXXXXXXXXXXX7
8	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX8	XXXXXXXXXXXXXXXXXXX8
9	ALPHANUMERIC CHARACTER	NONE
10	ALPHANUMERIC CHARACTER	NONE

*DIMENSIONS INDICATE THE MAXIMUM ALLOWABLE AREA FOR MARKING

ALGLE PROGRAM	TITLE COUPON	DRAWING NUMBER S1A	REVISION D	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 4340 PER AMS 6415	DATE 2/28/03	SHEET 3 OF 4	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

TABLE III: MARK REQUIREMENTS

1. DEEP LASER ENGRAVE MARKS IN DETAIL III PER NASA-HDBK-6003 (P027)
2. DOT PEEN MARKS IN DETAIL III PER NASA-HDBK-6003 (P027)
3. MICRO MILL MARKS IN DETAIL III PER NASA-HDBK-6003 (P027)
4. VIBROPEEN MARKS IN DETAIL III PER OO-ALC/MANPP PROCEDURE
5. IMPRESSION STAMP MARKS IN DETAIL III PER OO-ALC/MANPP PROCEDURE

6 – 10 NOT APPLICABLE

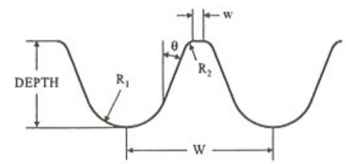
DETAIL III: NOTES AND CELL DETAIL

III.1 LINES AND BOXES INDICATE LOCATIONS FOR MARKS

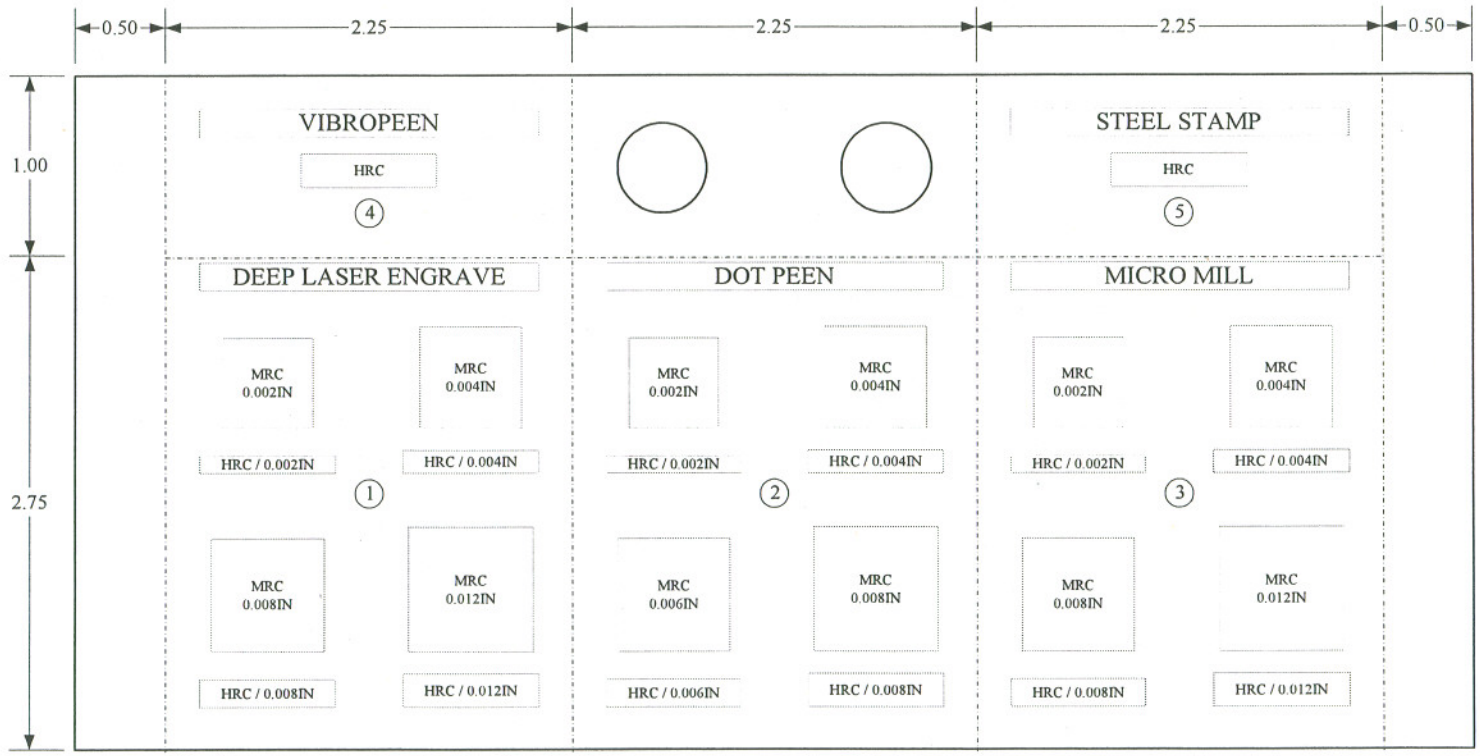
III.2 MRC / MACHINE READABLE CODE: 22 X 22 DATA MATRIX / DEPTH INDICATED IN BOXES

III.3 HRC / HUMAN READABLE CODE: 10 NUMBERS / DEPTH INDICATED IN BOXES
EACH HRC SHALL BE A DIFFERENT RANDOM NUMBER

III.4 MRC AND HRC CELLS SHALL INCLUDE RADII AND TAPERS AS SHOWN



DETAIL III: FIGURE



ALGLE PROGRAM	TITLE: COUPON	DRAWING NUMBER: S1A	REVISION: D	DIMENSIONS: ALL DIMENSIONS IN INCHES	TOLERANCES: UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN: JOHN COATES
DPM EVALUATION	MATERIAL: 4340 PER AMS 6415	DATE: 2/28/03	SHEET: 4 OF 4	SCALE: NOT TO SCALE		CHECKED: FRANK ZUECH

COUPON A1A

COUPON A1A REVISION D HISTORY

New: Unmarked Coupon

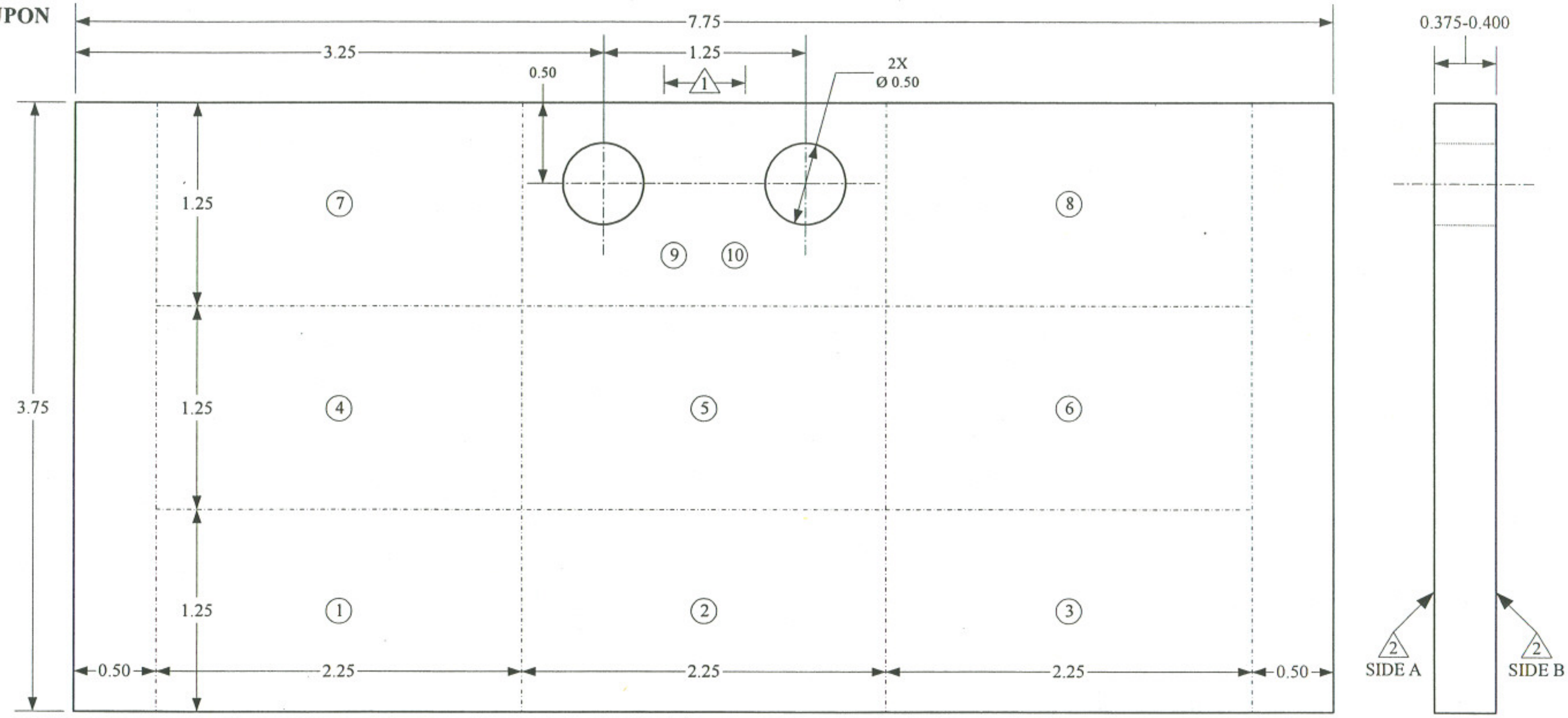
A: Unmarked Coupon: Drawing Configuration Change

B: Unmarked Coupon: Material Change

C: Marked Coupon: A1A-01 to A1A-16

D: Marked Coupon: A1A-17 to A1A-20

COUPON



NOTES

1. SERIALIZE THE COUPONS A1A-01 TO A1A-22 ON TOP EDGE AT NOTED LOCATION USING0.25 IMPRESSION STAMP, 0.004-0.008 DEEP
2. 0.025 125/64 M
3. BREAK ALL SHARP EDGES 0.005-0.015
4. FLUORESCENT PENETRANT INSPECT PER ASTM E1417
5. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM CONDUCTIVITY TESTS PER MIL-STD-1537
6. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM SURFACE ROUGHNESS MEASUREMENT PER ASME B46.1

1 – 10
i) FOR COUPONS A1A-01 TO A1A-04: MARK SIDE A WITH DATA MATRIX™ SYMBOLS PER TABLE I REQUIREMENTS
ii) FOR COUPONS A1A-05 TO A1A-16: MARK SIDE A WITH DATA MATRIX™ SYMBOLS PER TABLE II REQUIREMENTS
iii) FOR COUPONS A1A-17 TO A1A-20: MARK SIDE A WITH DATA MATRIX™ SYMBOLS PER TABLE III REQUREMENTS

ALGLE PROGRAM	TITLE COUPON	DRAWING NUMBER A1A	REVISION D	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 7075-T7351 PER AMS 4078 (0.5 INCH PLATE)	DATE 2/28/03	SHEET 1 OF 4	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

TABLE I: DATA MATRIX™ OPTIMIZATION

1 – 10 i) AT LEAST ONE COUPON MUST CONTAIN THE MINIMUM NUMBER OF MARKS
ii) FOR THE MINIMUM NUMBER OF MARKS, USE DIFFERENT DPM PROCESS CONTROLS

1 DOT PEEN A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

2 LASERSHOT™ PEEN A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

3 MICRO-MILL A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

4 LASER BOND A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

5 LASER ETCH A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

6 GAS ASSIST LASER ETCH (GALE) A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

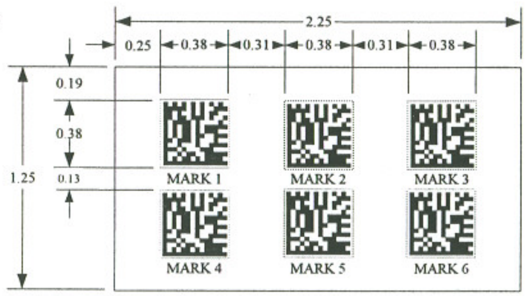
7 LASER ENGRAVE A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

8 LASER INDUCE SURFACE IMPROVEMENT (LISI) A MINIMUM OF 6 MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)

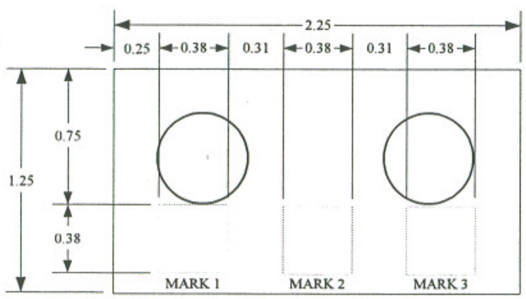
9 VIBRA-ETCH A MINIMUM OF 3 MARKS IN DETAIL I.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)

10 IMPRESSION STAMP A MINIMUM OF 3 MARKS IN DETAIL I.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)

DETAIL I.A*



DETAIL I.B*



	MARK DATA
1	XXXXXXXXXX
2	XXXXXXXXXX
3	XXXXXXXXXX
4	XXXXXXXXXX
5	XXXXXXXXXX
6	XXXXXXXXXX
7	XXXXXXXXXX
8	XXXXXXXXXX
9	ALPHANUMERIC CHARACTER
10	ALPHANUMERIC CHARACTER

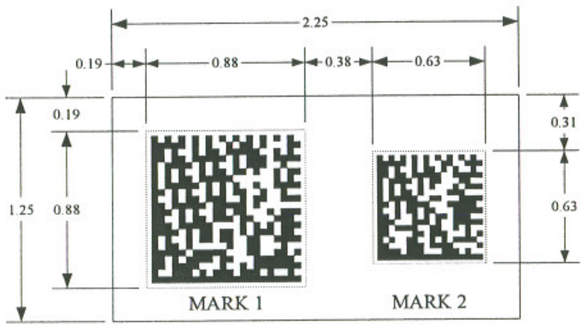
*DIMENSIONS INDICATE THE MAXIMUM ALLOWABLE AREA FOR MARKING

ALGLE PROGRAM	TITLE COUPON	DRAWING NUMBER A1A	REVISION D	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 7075-T7351 PER AMS 4078 (0.5 INCH PLATE)	DATE 2/28/03	SHEET 2 OF 4	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

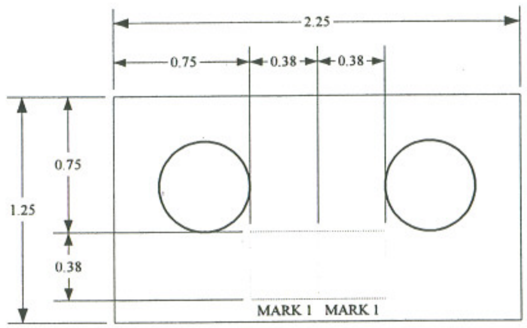
TABLE II: DATA MATRIX™ REQUIREMENTS

1. DOT PEEN MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
2. LASERSHOT™ PEEN MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
3. MICRO-MILL MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027), 0.024-0.032 DEEP
4. LASER BOND MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027)
5. LASER ETCH MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027)
6. GAS ASSIST LASER ETCH (GALE) MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027)
7. LASER ENGRAVE MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
8. LASER INDUCE SURFACE IMPROVEMENT (LISI) MARKS IN DETAIL II.A PER NASA-HDBK-6003 (P027)
9. VIBRA-ETCH MARK IN DETAIL II.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)
10. IMPRESSION STAMP MARK IN DETAIL II.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)

DETAIL II.A*



DETAIL II.B*



	MARK DATA	
	MARK 1 DATA	MARK 2 DATA
1	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX1	XXXXXXXXXXXXXXXXXXX1
2	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX2	XXXXXXXXXXXXXXXXXXX2
3	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX3	XXXXXXXXXXXXXXXXXXX3
4	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX4	XXXXXXXXXXXXXXXXXXX4
5	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX5	XXXXXXXXXXXXXXXXXXX5
6	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX6	XXXXXXXXXXXXXXXXXXX6
7	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX7	XXXXXXXXXXXXXXXXXXX7
8	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX8	XXXXXXXXXXXXXXXXXXX8
9	ALPHANUMERIC CHARACTER	NONE
10	ALPHANUMERIC CHARACTER	NONE

*DIMENSIONS INDICATE THE MAXIMUM ALLOWABLE AREA FOR MARKING

ALGLE PROGRAM	TITLE: COUPON	DRAWING NUMBER: A1A	REVISION: D	DIMENSIONS: ALL DIMENSIONS IN INCHES	TOLERANCES: UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN: JOHN COATES
DPM EVALUATION	MATERIAL: 7075-T7351 PER AMS 4078 (0.5 INCH PLATE)	DATE: 2/28/03	SHEET: 3 OF 4	SCALE: NOT TO SCALE		CHECKED: FRANK ZUECH

TABLE III: MARK REQUIREMENTS

1. DEEP LASER ENGRAVE MARKS IN DETAIL III PER NASA-HDBK-6003 (P027)
2. DOT PEEN MARKS IN DETAIL III PER NASA-HDBK-6003 (P027)
3. MICRO MILL MARKS IN DETAIL III PER NASA-HDBK-6003 (P027)
4. VIBROPEEN MARKS IN DETAIL III PER OO-ALC/MANPP PROCEDURE
5. IMPRESSION STAMP MARKS IN DETAIL III PER OO-ALC/MANPP PROCEDURE

6 – 10 NOT APPLICABLE

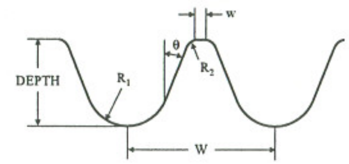
DETAIL III: NOTES AND CELL DETAIL

III.1 LINES AND BOXES INDICATE LOCATIONS FOR MARKS

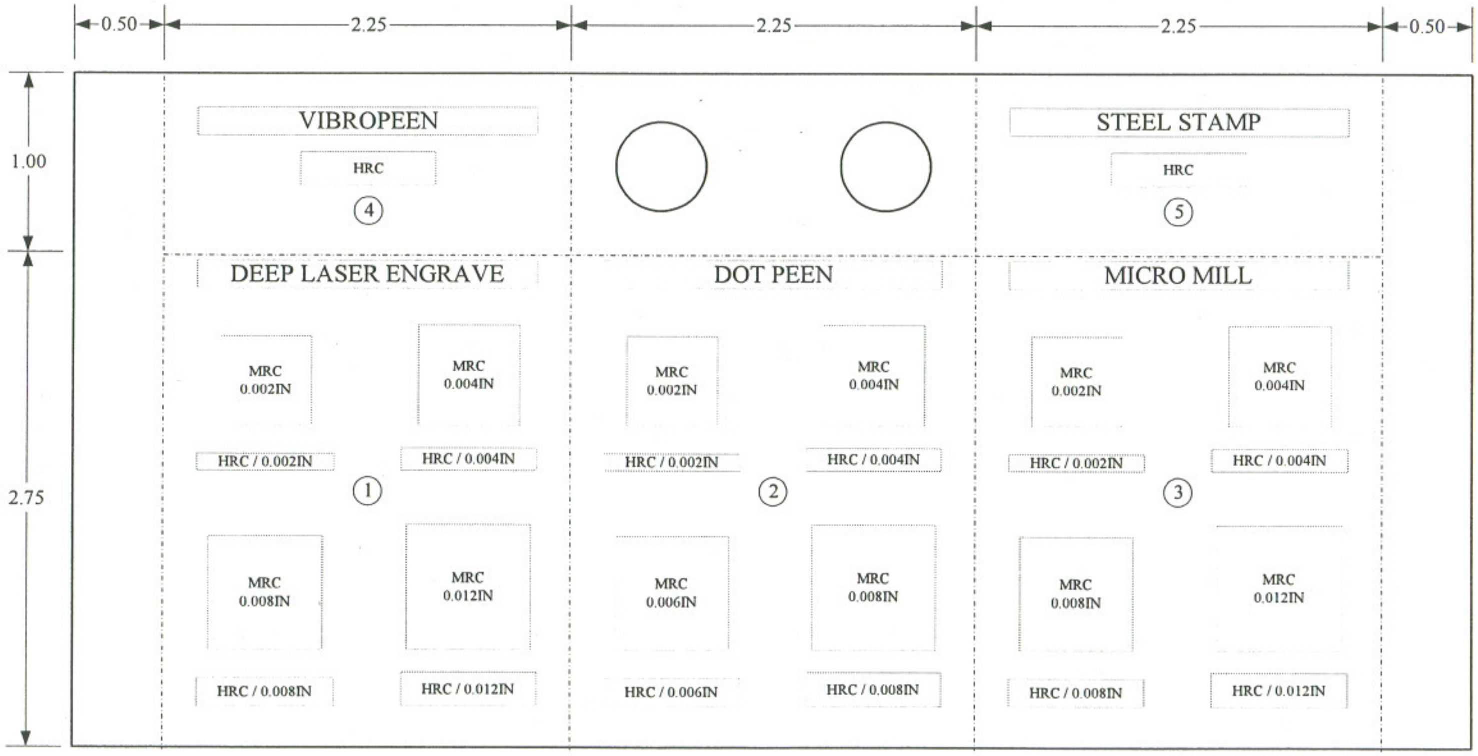
III.2 MRC / MACHINE READABLE CODE: 22 X 22 DATA MATRIX / DEPTH INDICATED IN BOXES

III.3 HRC / HUMAN READABLE CODE: 10 NUMBERS / DEPTH INDICATED IN BOXES
EACH HRC SHALL BE A DIFFERENT RANDOM NUMBER

III.4 MRC AND HRC CELLS SHALL INCLUDE RADII AND TAPERS AS SHOWN



DETAIL III: FIGURE



ALGLE PROGRAM (ALGLE)	TITLE: COUPON	DRAWING NUMBER: A1A	REVISION: D	DIMENSIONS: ALL DIMENSIONS IN INCHES	TOLERANCES: UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN: JOHN COATES
DPM EVALUATION	MATERIAL 7075-T7351 PER AMS 4078 (0.5 INCH PLATE)	DATE: 2/28/03	SHEET: 4 OF 4	SCALE: NOT TO SCALE		CHECKED: FRANK ZUECH